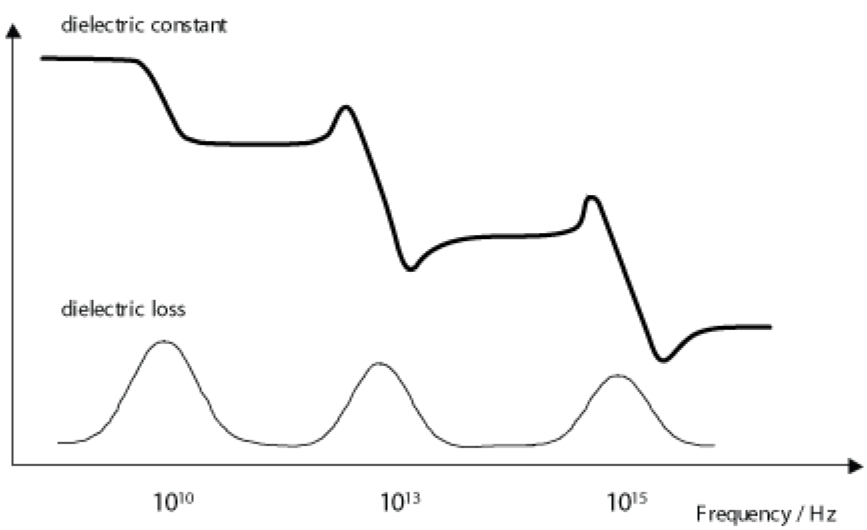
Loss and Applications in Dielectrics

Loss in dielectrics :

An efficient dielectric supports a varying charge with minimal dissipation of energy in the form of heat. There are two main forms of loss that may dissipate energy within a dielectric. In conduction loss, a flow of charge through the material causes energy dissipation. Dielectric loss is the dissipation of energy through the movement of charges in an alternating electromagnetic field as polarisation switches direction.

Dielectric loss is especially high around the relaxation or resonance frequencies of the polarisation mechanisms as the polarisation lags behind the applied field, causing an interaction between the field and the dielectric's polarisation that results in heating. This is illustrated by the diagram below (recall that the dielectric constant drops as each polarisation mechanism becomes unable to keep up with the switching electric field.)



Dielectric loss tends to be higher in materials with higher dielectric constants. This is the downside of using these materials in practical applications.

Dielectric loss is utilised to heat food in a microwave oven: the frequency of the microwaves used is close to the relaxation frequency of the orientational polarisation mechanism in water, meaning that any water present absorbs a lot of energy that is then dissipated as heat. The exact frequency used is slightly away from the frequency at which maximum dielectric loss occurs in water to ensure that the microwaves are not all absorbed by the first layer of water they encounter, therefore allowing more even heating of the food.

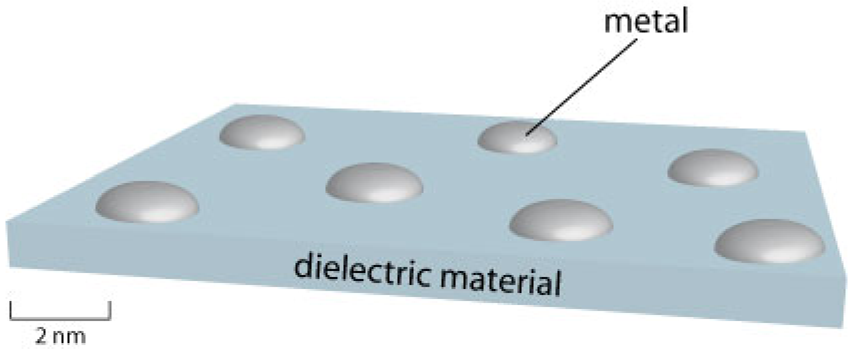
Applications of dielectrics

A major use of dielectrics is in fabricating capacitors. These have many uses including storage of energy in the electric field between the plates, filtering out noise from signals as part of a resonant circuit, and supplying a burst of power to another component. The TLP on ferroelectrics shows how the last of these functions is utilised in a camera flash system.

The larger the dielectric constant, the more charge the capacitor can store in a given field, therefore ceramics with non-centrosymmetric structures, such as the titanates of group 2 metals, are commonly used. In practice, the material in a capacitor is in fact often a mixture of several such ceramics. This is due to the variation of the dielectric constant with temperature discussed earlier. It is generally desirable for the capacitance to be relatively independent of temperature; therefore modern capacitors combine several materials with different temperature dependences, resulting in a capacitance that shows only small, approximately linear temperature-related variations.

Of course in some cases a low dielectric loss is more important than a high capacitance, and therefore materials with lower values of κ – and correspondingly lower dielectric losses – may be used for these situations.

Some applications of dielectrics rely on their electrically insulating properties rather than ability to store charge, so high electrical resistivity and low dielectric loss are the most desirable properties here. The most obvious of these uses is insulation for wires, cables etc., but there are also applications in sensor devices. For example, it is possible to make a type of strain gauge by evaporating a small amount of metal onto the surface of a thin sheet of dielectric material.



Electrons may travel across the metal by normal conduction, and through the intervening dielectric material by a phenomenon known as quantum tunnelling. A mathematical treatment of this phenomenon is outside the scope of this TLP; simply note that it allows particles to travel between two “permitted” regions that are separated by a “forbidden” region and that the extent to which tunnelling occurs decreases sharply as distance between the permitted regions increases. In this case the permitted regions are the solidified metal droplets, and the forbidden region is the high-resistance dielectric material.

If the dielectric material is strained, it will bow causing the distances between the metal islands to change. This has a large impact on the extent to which electrons can tunnel between the islands, and thus a large change in current is observed. Therefore the above device makes an effective strain gauge.

http://www.doitpoms.ac.uk/tlplib/dielectrics/loss.php